LETTER Special Section on Spread Spectrum Techniques and Applications

A Nonlinear Blind Adaptive Receiver for DS/CDMA Systems

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SUMMARY In this letter, we propose a blind adaptive receiver with nonlinear structure for DS/CDMA communication systems. The proposed receiver requires the signature waveform and timing for only the desired user. It is shown that the blind adaptation is equivalent to the adaptation with the training signal and the function to be minimized has no local minima.

key words: *near-far problem, Volterra filter, multiple access interference, interference cancellation, polynomial approximation*

1. Introduction

In code-division multiple-access (CDMA) communications, multiple access interference from other users leads to performance degradation. Several techniques to cancel the interference at the receiver have been studied by many researchers [1]. It is known that nonlinear structure in the receiver is required to achieve the optimum performance because of the nonlinearity of the optimum decision boundary [2].

Recently, adaptive receivers for CDMA systems are very actively being investigated [1]. The adaptive receivers can be adopted when channel parameters, e.g., spreading codes and received signal amplitudes, are unknown and/or time variant. In particular, blind adaptive receivers which does not require any training signals become a center of attraction [3], [4]. However, the conventional blind adaptive receiver [3], [4] has linear structure so that its performance is limited. In this letter, we propose a blind adaptive receiver with nonlinear structure.

2. Nonlinear Blind Adaptive Receiver

2.1 Receiver Structure

Consider a single user receiver for direct sequence (DS)/CDMA systems. In the receiver, the signature waveform and timing for only the desired user are assumed to be known. That is, the receiver has no knowledge beyond that assumed by the conventional matched filter receiver.

The structure of the nonlinear blind adaptive receiver is shown in Fig. 1. The receiver consists of a matched filter, orthogonal filters and an adaptive filter.

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The matched filter matches to the spreading sequence of the desired user. The filter coefficients of the orthogonal filters are orthogonal to the spreading sequence of the desired user. The adaptive filter is a nonlinear adaptive filter. The proposed receiver is an extension of the linear blind adaptive receiver proposed by Fukawa et al. [3]. In the linear receiver, the adaptive filter in Fig. 1 is a linear adaptive filter.

The received signal can be expressed as

$$r(t) = \sum_{p} \sum_{k=1}^{K} A_k b_k(p) s_k(t - pT_b - \tau_k) + n(t) \quad (1)$$

where $A_k, b_k(p) \in \{+1, -1\}$ is the signal amplitude and the pth information data of the kth user, $n(t)$ is white Gaussian noise, K is the number of users, T_b is the bit duration and $s_k(t)$ is the signature waveform defined as

$$s_k(t) = \sum_{l=1}^{L} a_{kl} P_{T_c}(t - (l-1)T_c) \quad (2)$$

where $\{a_{kl}\}$ is the kth user's spreading sequence, $P_{T_c}(t)$ is the chip waveform, T_c is the chip duration and L is the length of the spreading sequence. The received signal is fed into the chip matched filter and sampled at the chip rate:

$$r_{kl}(p) = \int_{pT_b+\tau_k+(l-1)T_c}^{pT_b+\tau_k+lT_c} r(t)dt, l = 1, \cdots, L. \quad (3)$$

For convenience, we will assume that the desired user is $k = 1$ and the bit index p will be omitted in the following. The output of the receiver, y_1, can be obtained by adding the nonlinear adaptive filter output, x_1, to the matched-filter output, z_1, as follows:

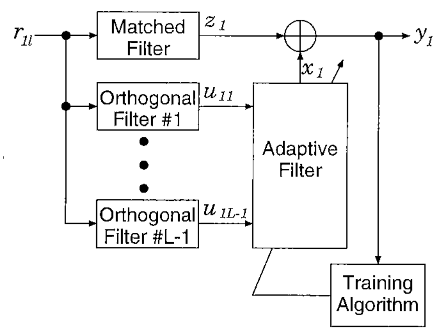

Fig. 1 Structure of blind adaptive receiver.

$$y_1 = z_1 + x_1, \tag{4}$$

with

$$z_1 = \sum_{l=1}^{L} r_{1l} a_{1l}, \tag{5}$$

$$x_1 = f(\boldsymbol{u}_1) \tag{6}$$

where $f(\cdot)$ is a nonlinear function and $\boldsymbol{u}_1$ is the $(L-1)\times 1$ orthogonal filter output vector whose mth element can be expressed as

$$u_{1m} = \sum_{l=1}^{L} r_{1l} c_{1ml}, m = 1, \cdots, L-1 \tag{7}$$

where $\{c_{1ml}\}$ is the coefficients of the mth orthogonal filter and satisfies

$$\sum_{l=1}^{L} a_{1l} c_{1ml} = 0, \tag{8}$$

$$\sum_{l=1}^{L} c_{1ml} c_{1m'l} = 0, m \neq m'. \tag{9}$$

The orthogonal filter can be obtained by the Gram-Schmidt orthogonalization procedure. The output of the matched filter contains the desired signal component, interference one and noise one. On the other hand, the output of the nonlinear filter contains the interference component and noise one. Thus, the interference component can be suppressed with preserving the desired component by adjusting the nonlinear adaptive filter to minimize the receiver output power.

The multilayer neural network and Volterra filter can be a candidate for the nonlinear adaptive filter. In the following, the blind adaptive receiver using the Volterra filter is considered.

2.2 Volterra Filter Implementation

The output of the Pth order Volterra filter in the receiver can be expressed as

$$\begin{aligned} x_1 &= \sum_{m_1=1}^{L-1} w_{11}(m_1) u_{1m_1} \\ &+ \sum_{m_1=1}^{L-1} \sum_{m_2=m_1}^{L-1} w_{12}(m_1, m_2) u_{1m_1} u_{1m_2} + \cdots \\ &+ \sum_{m_1=1}^{L-1} \cdots \sum_{m_P=m_{P-1}}^{L-1} w_{1P}(m_1, \cdots, m_P) u_{1m_1} \cdots u_{1m_P} \\ &= \boldsymbol{w}_1^T \boldsymbol{v}_1 \end{aligned} \tag{10}$$

where $\boldsymbol{w}_1 = [w_{11}(1), \cdots, w_{1p}(m_1, \cdots, m_p), \cdots, w_{1P}(L-1, \cdots, L-1)]^T$ is the adjustable parameter vector and $\boldsymbol{v}_1 = [u_{11}, \cdots, u_{1m_1} \cdots u_{1m_p}, \cdots, u_{1L-1} \cdots u_{1L-1}]^T$ is the input vector. The receiver using the Volterra filter corresponds to polynomial approximation of the optimum detection. The proposed receiver is identical to the conventional linear blind receiver when $P = 1$.

Now, consider the receiver output power $J(\boldsymbol{w}_1)$ and the mean square error $E(\boldsymbol{w}_1)$ defined by

$$J(\boldsymbol{w}_1) = E[y_1^2] \tag{11}$$

and

$$E(\boldsymbol{w}_1) = E[(A_1 b_1 - y_1)^2]. \tag{12}$$

Then we have

$$E(\boldsymbol{w}_1) = J(\boldsymbol{w}_1) - A_1^2 \tag{13}$$

as in the case of the linear receiver [4]. This implies that the training signal is not required to minimize the mean square error.

Moreover, the parameter which minimizes the receiver output power is the same as the parameter which minimizes the mean square error. Because the gradient of $J(\boldsymbol{w}_1)$ with respect to $\boldsymbol{w}_1$ is equal to that of $E(\boldsymbol{w}_1)$. The optimum parameter can be expressed as

$$\boldsymbol{w}_{1opt} = -\boldsymbol{R}_1^{-1} \boldsymbol{p}_1 \tag{14}$$

where

$$\boldsymbol{R}_1 = E[\boldsymbol{v}_1 \boldsymbol{v}_1^T], \tag{15}$$

$$\boldsymbol{p}_1 = E[z_1 \boldsymbol{v}_1]. \tag{16}$$

Lastly, it is worth mentioning about the shape of the receiver output power function $J(\boldsymbol{w}_1)$. As in the case of the linear receiver [4], the function is convex because

$$\begin{aligned} &J(\alpha \boldsymbol{w}_1^{(a)} + (1-\alpha) \boldsymbol{w}_1^{(b)}) \\ &= \alpha J(\boldsymbol{w}_1^{(a)}) + (1-\alpha) J(\boldsymbol{w}_1^{(b)}) \\ &\quad -\alpha(1-\alpha) E[\{(\boldsymbol{w}_1^{(a)} - \boldsymbol{w}_1^{(b)}) \boldsymbol{v}_1\}^2] \end{aligned} \tag{17}$$

where $0 < \alpha < 1$. This implies that the receiver output power function has no local minima.

3. Simulation Results

Simple simulation was carried out. A four-user synchronous DS/CDMA system was assumed. Gold sequences of length seven were chosen for spreading sequences. RLS algorithm was used as an adaptation algorithm. The nonlinear filter was the 3rd-order Volterra filter. It was assumed that the signals of the users except the 1st (desired) user have equal energy per bit. The interference signal energy to the desired signal energy ratio was 10 dB.

Figure 2 shows the bit error rate for the 1st user of the proposed nonlinear blind, linear blind and matched

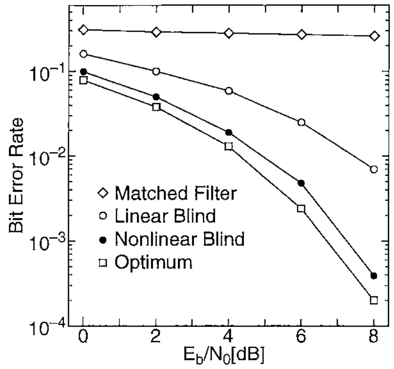

Fig. 2 Bit error rate.

filter receiver. The result for the optimum multiuser receiver [5] which has the knowledge of the signature waveforms, timings and amplitudes for all users is also shown. Although we can not conclude near optimality of the proposed receiver from the comparison with the optimum multiuser receiver because of difference in the problem formulation, comparison with the other two shows the advantage of the proposed receiver.

4. Conclusion

A blind adaptive receiver with nonlinear structure has been proposed. The proposed receiver only requires the signature waveform and timing of the desired user. It has been shown that when the Volterra filter is used as a nonlinear filter the blind adaptation is equivalent to the adaptation with the training signal and the function to be minimized has no local minima as in the case of the linear case.

We will investigate appropriate nonlinear filter structure and adaptive algorithm. Moreover, the performance evaluation of the proposed receiver in time variant channels is the subject for a future study.

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